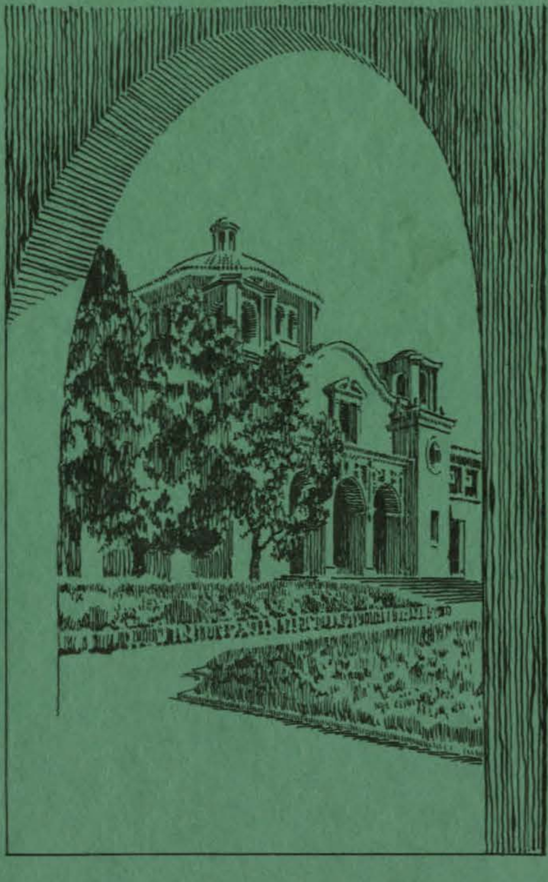
GLIMPSES OF THE WORK OF THE COOPERATIVE HYDRAULICS LABORATORY



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SOIL CONSERVATION SERVICE
AND
THE CALIFORNIA INSTITUTE OF TECHNOLOGY

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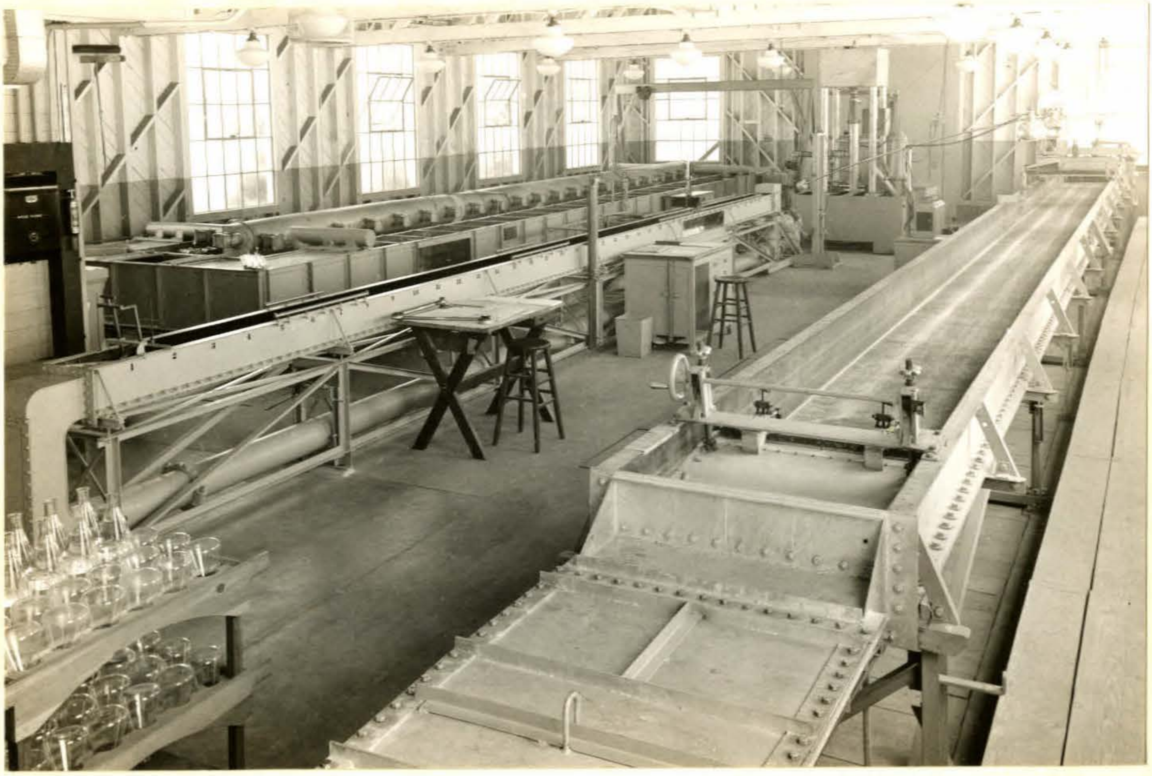


THE MAIN LABORATORY

ABOUT THIS BOOKLET

This booklet is presented with the compliments of the California Institute of Technology to those attending the meetings of the Soil Conservation Service held on the campus at Pasadena, February 14 to 19, 1944.

Its purpose is two-fold: (1) To acquaint our guests with the Cooperative Hydraulics Laboratory and the work of its staff, and (2) to provide notes on the discussions presented by members of the staff at these meetings.

THE COOPERATIVE HYDRAULICS LABORATORY OF THE SOIL CONSERVATION SERVICE AND THE CALIFORNIA INSTITUTE OF TECHNOLOGY

ROBERT T. KNAPP
COOPERATIVE AGENT

I. LABORATORY OBJECTIVE

The basic objective of the Cooperative Hydraulics Laboratory is to investigate soil conservation problems that involve hydraulics, and if satisfactory solutions are obtained, to assist in developing practical applications for the use of the Operations Division of the Service. The most outstanding difference between normal hydraulics and hydraulics as applied to soil conservation is that normal hydraulics is restricted to the flow of clear water; whereas, in soil conservation the problems are complicated by the presence of sediment and debris. Therefore, it is natural that much of the Laboratory's work has dealt with the interaction between flowing fluids and entrained sediment. However, the Laboratory has never been restricted solely to the study of sediment transportation problems, but, like Operations, has also been interested in hydraulic structures to measure and control clarified flows.

II. LABORATORY HISTORY

The Cooperative Laboratory was initiated by and established at the request of the Soil Conservation Service in the Spring of 1935. The concept of the Laboratory originated with Dr. W. C. Lowdermilk, then Associate Chief of the Soil Conservation Service in charge of Research. It was established as the Hydraulics Laboratory of the Sedimentation Section of the Research Division. Mr. H. M. Eakin was the Chief of this Division and was closely connected with the development of the Laboratory until his death. His activities were carried on by Mr. G.C. Dobson until 1942. Under the direction of Dr. M. L. Nichols, Chief of Research, the scope of the project has gradually broadened until it may now be considered a general hydraulics laboratory for the Research Division.

The Laboratory building was erected in 1936. It was designed and engineered by the Laboratory staff. Dr. V. A. Vanoni has been the Project Supervisor since its inception. During the first period when both the Laboratory and the Service itself were young, a large percentage of the project's time was spent on an intensive study of general soil conservation problems, particularly those concerning sediment transportation. The basic purpose was to build up a background of knowledge to make it possible to attack and solve field problems. During this period of the Laboratory's existence, it might be hazarded that the Operations Division was undergoing a like experience, i.e., delineating its problems and building up a background of knowledge to aid in their solution. From the beginning the Laboratory attempted to keep in intimate contact with the field problems of the Service and endeavored to be of assistance in their solution. At first comparatively few tangible benefits resulted from this relationship, probably due both to lack of knowledge on the part of the Laboratory and inability on the part of the Operations projects to recognize and define their problems. However, as time went on, these obstacles began to disappear as both became more competent. Thus it may be said that during the first period of the Laboratory's existence, the great majority of its time and energy was devoted to the study of pure research problems in soil conservation. The second, and present, period, which began a few years ago, is characterized by the devotion of a very substantial part of the Laboratory's activities to the solution of specific field problems for the various Operations regions. These specific field studies are, of course, carried on in parallel with and complement the fundamental investigations. It is very important that the fundamental studies of sediment transportation and other soil conservation problems be carried on continuously because it is through such investigations that increased knowledge and power will be obtained to devise new and more satisfactory solutions to the many difficult and complicated problems that our Service encounters continuously in the field.

III. LABORATORY ACTIVITIES

The most important work of the Laboratory during the first period was Dr. Vanoni's study of suspended load transportation with auxiliary investigations by Rouse, Christensen, and Van Driest. This work, combined with the observations from many field trips, helped to build an understanding of the mechanism of soil erosion.

During this period work was started on the behavior of density currents in reservoirs. Mr. H. S. Bell, whose discussion on this subject also appears in this set of abstracts, has been associated with the density current study from its commencement.

Another early phase of the work was the investigation of the nature of wind erosion. This was carried on under the general direction of Prof. Th. von Karman by Dr. Malina.

It will be noted that all three of these studies have the same theme: the transportation of sediment by flowing fluids. This is the most important and most complicated of the hydraulics problems confronting soil conservationists, and the one about which the least is known. Therefore, in its various manifestations, it is safe to say that it will continue to be in the future, as it has been in the past, the chief interest of this Laboratory.

The beginning of the second period of the Laboratory's progress was marked by the undertaking of the development of a standard drop structure design for the then Operations Region 10. Since the laboratory staff was small and heavily loaded, it was arranged that the Region should send an engineer to assist in the investigation. The Laboratory felt that the results of this arrangement were so successful that it has been its fixed policy to request that when a study is to be made for another branch of the Service, that that branch send a representative to assist in the study. The two main benefits resulting from this practice are that their representative brings to the Laboratory accurate knowledge of the details of the field problem, and when the study is finished, he takes back to the field a thorough understanding of both the advantage and limitation of the results of the Laboratory investigation.

This drop structure study was the first of a series of energy dissipation structures that have been studied for Operations. In addition, developments of flow measuring devices, samplers, and similar instrumental equipment has been undertaken.

IV. BRIEF OUTLINE OF PRESENT ACTIVITIES

The coming of war caused a change in the Laboratory activities. Work on basic research projects has been reduced to a minimum in order to concentrate on work which could assist immediately in the war effort, primarily in the food production program. Thus, wind erosion studies have been discontinued for the duration and density current and sediment transportation studies have been retarded.

In the future, 1943 will probably be characterized for the Laboratory as the year of the spillway models. Work started in the early Spring, and by the end of June four spillway models had been studied for Region Four. These were existing structures that had been designed by another agency and through a reorganization had been turned over to the Soil Conservation Service to operate. In each case, operation had proved to be unsatisfactory and dangerous and some of the structures had already been badly damaged. The troubles were largely hydraulic rather than structural since the water did not do what the designers had supposed it would. The flow left the structure and caused undermining and failures in ways that had not been anticipated. The purpose of the studies was to determine the simplest and most economical methods of reconstruction which would provide an adequate hydraulic design for the spillways and the stilling basins below them. Incidentally, these spillways were large structures and the loss to the government through the damage that has been done, plus the cost of reconstructing them, is more than the cost of operating this Laboratory for several decades.

Two other spillway investigations for Regions 6 and 7 were carried out during the year. These differed from the first group in that they were both design studies made in advance of actual construction. This gave the Laboratory a better opportunity to make constructive suggestions.

These spillway studies were the Laboratory's most specific work, and therefore the most limited in application. The work on the baffle type energy dissipators for pipe outlets, which was completed during 1943, was more general in scope. It was a sequel to the work on standardized drop structure design. The objective has been to develop standard methods of designing energy dissipators to meet a wide range of conditions. Although the relationship between Operations and the Laboratory is less intimate than it is, for example, on the individual spillway studies, and the results may not be so immediately applicable, it is felt that this type of project represents a more effective use of the Laboratory and, in the long run, is probably more valuable to the Service because the results of it can be applied to innumerable structures without additional laboratory work. Another study intermediate in character between the spillway and the pipe outlet has been the development of a flow meter for use in irrigation risers. It is probable that this device is more specialized and thus less widely applicable than the energy dissipator, but is, of course, of much more general use than the individual spillway studies.

An interesting development in the program of density current investigation has come through contacts with a local power company. This has resulted in some valuable field measurements of density current characteristics and their possible utilization in reservoirs. Arrangements have been completed for the carrying out of a rather extended investigation this Spring.

The work on sediment transportation has been given additional impetus by the addition of Dr. H. A. Einstein to the Laboratory staff. He has been studying this problem for several years on another project of the Research Division.

This concludes the brief review of the work of the Cooperative Laboratory. Incidentally, this name comes from the fact that it is a joint, or cooperative, undertaking of the Soil Conservation Service and the California Institute of Technology. However, it is hoped that the various branches of the Service will always feel in their relations with this Laboratory that it lives up literally to its name.

DENSITY CURRENTS

HUGH STEVENS BELL

It is now more than eight years since that November day when observers at Boulder Dam were surprised to see muddy water discharging from an apparently clear blue lake. Within the next few months this phenomenon was repeated several times and gave rise, in engineering circles, to much speculation as to its cause.

To those who knew about density currents (Fig. 1) there was nothing mysterious or unnatural about the passage of a stream of turbid water through a clear reservoir. Half a century earlier a group of Swiss naturalists became interested in similar flows in Lakes Constance and Geneva. For twenty years there had been reports of muddy underflows through reservoirs of our own Southwest. American scientists and engineers, however, showed little or no interest and, consequently, "those who knew" were not numerous.

The events at Boulder Dam caught the attention and stirred the imagination of workers in several fields. The National Research Council appointed a Density Current Committee, of which Dr. Knapp is a member. At that time, also, the Laboratory began studying density current phenomena because it appeared that they might be of importance in the problem of conserving reservoir storage capacity, a field in which the Soil Conservation Service was already vitally interested. It is only honest to confess that the staff has been as much surprised as anyone to find that density currents are the chief agents for transporting very fine sediment by air and water.

Investigations at the Laboratory make it evident that the "black blizzards" (Fig. 2) of the prairies, the "fiery clouds" (Fig. 3) of volcanoes, the "underflows" and "overflows" (Fig. 4) in reservoirs and on the oceans, are all manifestations of a single phenomenon. Each is a turbid density current composed of a suspension of sediment in a fluid. All are important in sediment transportation, the problem in which the Laboratory has been primarily interested since its inception.

Although atmospheric density currents may carry rather coarse particles because of the high velocity of strong winds, density currents in reservoirs ordinarily move slowly. Their velocity is more apt to be inches per second than feet per second. For this reason the turbulence is able to keep only the finer sediment in suspension, and the material transported consists almost entirely of fine silt, clay and colloidal particles. In large reservoirs having bottom slopes of less than 5 feet per mile, particles with diameters as great as 0.001 inch do not remain in suspension long enough to be carried to the dam.

Field data on the work done by turbid density currents are not abundant but, because of the excellent work of the Bureau of Reclamation, we know that about 18% of all sediment brought to Lake Mead is transported by density currents into the lower end of the reservoir where it forms a great submerged sludge pool. Fig. 5 shows variations in the depth and sediment concentration in this pool over a period of two years.

This fine sediment is accumulating against Boulder Dam at the rate of about 45,000,000 tons per year. It has been estimated that these deposits will never have a sediment concentration greater than 30 pounds per cubic foot within the lifetime of the Boulder Dam project. Since the mean specific weight of all sediment deposited at Lake Mead is about 60 pounds per cubic foot, it is evident that the density current deposits, although only 18% by weight, will account for approximately 36% of the loss in storage capacity.

A few years ago there were many who thought it might be possible to prevent or destroy density currents. The Laboratory's findings do not support this idea but indicate it will be wiser to use our energies in trying to cooperate with them by revising reservoir operating techniques. Obviously if sediments transported by density currents are vented instead of being stored, the useful life of any reservoir that impounds muddy water can be prolonged.

The nation rapidly is using up its supply of desirable sites for reservoirs. Many communities already know that reservoir storage capacity once lost is usually lost forever. In the future the duties of the operators of small reservoirs may include the creation of density currents by mechanical means. By this method the life of many reservoirs could be increased greatly, and the usefulness of a few might be prolonged almost forever.

In the quarter-century since World War I the science of weather prediction has been rebuilt to the benefit of all. This advance was made possible by new knowledge of atmospheric density currents. The meteorologists did not change the weather but, by learning how to predict it more accurately, made it possible for mankind to cooperate more easily. Perhaps the next quarter-century will see a similar advance in the technique of reservoir operation.

FIG. 1. A TURBID DENSITY CURRENT IN A LABORATORY RESERVOIR.

FIG. 2. A NEBRASKA DUST STORM. THE FLOW OF DUST-LADEN AIR WAS ABOUT 2,000 FEET DEEP.

FIG. 3. A "FIERY CLOUD" AT MOUNT PELEÉ. ONE FROM THE SAME MOUNTAIN DESTROYED THE ENTIRE CITY OF SAINT PIERRE IN MAY 1902.

FIG. 4. FLOOD WATER FROM THREE STREAMS SPREADING ON THE SURFACE OF THE PACIFIC NEAR DEL MAR, CALIF.

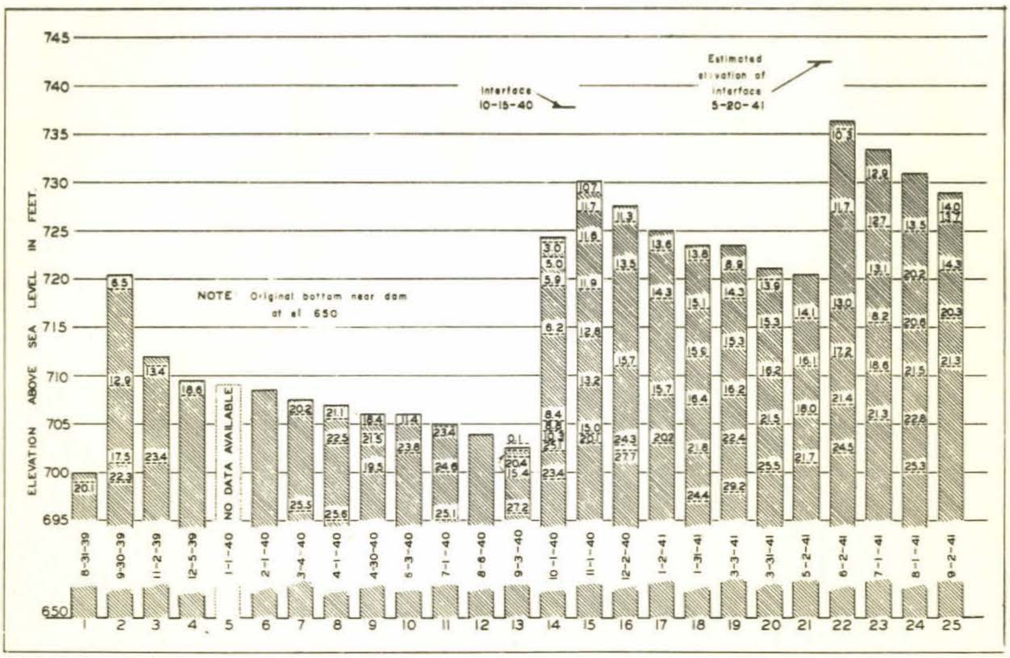


FIG. 5. DIAGRAM SHOWING MONTHLY VARIATIONS IN THE DEPTH OF MUDDY WATER IN A SUBMERGED POOL AT BOULDER DAM. NUMERALS IN THE COLUMNS SHOW SEDIMENT CONCENTRATIONS, IN POUNDS PER CUBIC FOOT, AT ELEVATIONS INDICATED BY DASHED LINES.

PHENOMENA OBSERVED IN SUSPENDED LOAD TRANSPORTATION

VITO A. VANONI

The objective of the sediment transportation studies of the Cooperative Laboratory is to determine the laws governing the phenomena involved with a view to furnishing information that will be of assistance in coping with practical erosion control problems. Sediment movement is intimately tied up with soil and water conservation and any basic knowledge on this subject should, therefore, be of assistance in this work. A common example of the need for additional scientific knowledge of sediment movement occurs in the design of the control works for channel systems. It is still not possible to predict for given conditions of flow and sediment load what will be the behavior of a system. As methods are developed for predicting flows and sediment loads with more certainty, and as sediment transportation laws are clarified, the solution of this and many other important sediment problems should become possible.

The understanding of the sediment transportation phenomena has progressed to the point where the important variables involved are recognized and some of the relations between these variables are known, at least for some conditions, but the complete solution to the problem is not yet available. For the purpose of studying the problem experimentally, it has been divided into two parts: (1) a study of the movement of material on or near the bed, and (2) a study of transportation of material in suspension in the fluid. The two parts are by no means independent and in nature one seldom occurs without the other. However, because the problem is so complicated, subdivision and simplification for purposes of laboratory study is a practical necessity. This discussion deals only with the material carried in suspension in the fluid after it has left the bed. The movement of material at and near the bed is covered in another discussion.

Material is held in suspension in the flow by the turbulence, which is produced at the channel boundaries by friction. This turbulence appears as whirls or eddies which diffuse throughout the cross section. Sediment caught in these eddies is moved within the cross section and may be kept in suspension. An observer at a fixed point in the flow will see the turbulence as fluctuations in the average velocity. The transverse fluctuations will appear as erratic variations in the direction of the velocity from right to left and up and down. The longitudinal fluctuations will cause the magnitude of the velocity to increase and decrease in an erratic manner.

Fig. 1 shows globules which have been injected into a flow at a point and spread by the turbulence as they are carried downstream. The globules have the same specific gravity as the water so they follow the flow exactly. Although the flow appears very smooth on the surface, the movement of the globules indicates that it is quite turbulent. The same action that spreads the globules also supports the sediment in suspension. The difference between the globules and the sediment is that sediment tends to settle out, and the cross components of turbulence must counteract this tendency. Under equilibrium conditions the tendency to settle is counteracted exactly by the supporting action of the turbulence.

From considerations of continuity, it can be seen that the action of the turbulence must be such as to transport as much fluid upward as downward through a given horizontal area. If the concentration above and below this area is the same, then no change in concentration results from a transfer of fluid across the area. But, if the concentrations are different, a transfer will result to the level having the lower concentration since the fluid arriving at this level brings more sediment than is taken away by the fluid moving in the opposite direction. The process that transfers the sediment also transfers the friction force applied at the boundaries of the channel to all of the filaments of flow in the cross section. Under equilibrium conditions for uniform flow, the component of the weight of the fluid tending to make it flow down the slope is exactly equal to the friction force applied at the boundaries.

Fig. 2 shows velocity profile curves for two flows of the same depth: one with clear water and the other with a suspended load whose distribution over the depth is shown at the right. The shaded area between velocity curves represents the increase in velocity due to the presence of the sediment. This increase cannot be attributed to the additional weight of the sediment since this is extremely small, and some other explanation must therefore be sought. Apparently, the effect of the sediment is to reduce the friction factor. However, if the effect were merely to reduce the channel friction, one would expect the two velocity curves to be parallel and displaced by a constant amount instead of being displaced by variable amounts at different levels. This peculiar phenomenon is explained by the action of the sediment in damping or reducing the intensity of the turbulence. Energy is required to keep the sediment from settling. This energy must come out of the turbulence and reduce its intensity, thus making it less effective in transmitting the boundary friction to the body of the flow and allowing a higher equilibrium velocity to occur. Experiments show that this damping depends on the amount and size of the material in suspension.

Fig. 3 shows the variation in sediment concentration with depth for two sizes of material. The ordinate scale gives the fraction of the distance from a reference level to the surface, and the absissa gives the concentration as a fraction of C_a, the concentration at the reference level. The curve at the extreme right is the experimental curve for the 0.100 mm. sand. The dotted curve is the result given by the theory for this same material and the curve at the left gives the distribution for 0.160 mm. sand which agrees exactly with the theoretical curve. The theoretical distribution formula, which is based on the assumption that the turbulence in sediment-laden flow is the same as with clear water, is shown on the graph of Fig. 2. Although the agreement between the measured and the theoretical distribution is fair considering the complexity of the problem, it still is not entirely satisfactory for practical use, and further study is necessary to improve the agreement. It must be noted that the sediment content is expressed in terms of the concentration at some arbitrary reference level. No means are at hand to predict the concentration at such a level, and before the problem can be solved completely, expressions for this quantity must be developed through further research. Further work on the sediment transportation program will include studies to find more accurate expressions for the sediment distribution and to determine the laws which give the total load that a flow will carry.

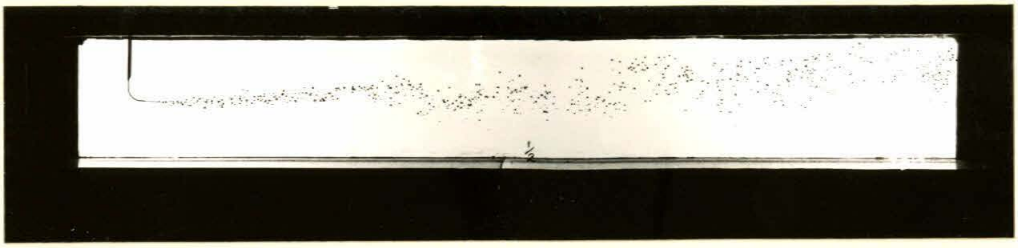


FIG. 1. PHOTOGRAPH SHOWING SPREADING OF GLOBULES IN TURBULENT FLOW AS THEY ARE CARRIED DOWNSTREAM FROM THE INJECTION POINT. GLOBULES HAVE THE SAME SPECIFIC GRAVITY AS THE WATER SO THEY FOLLOW ITS MOTION EXACTLY.

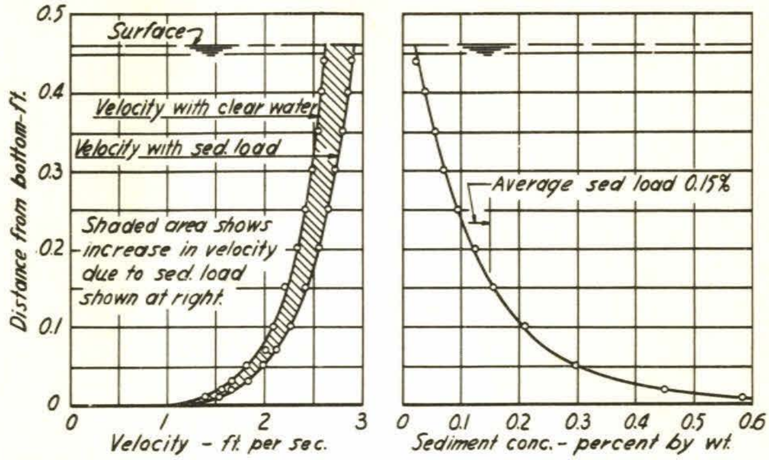


FIG. 2. VELOCITY AND SEDIMENT DISTRIBUTION CURVES FOR FLOW IN LABORATORY FLUME.

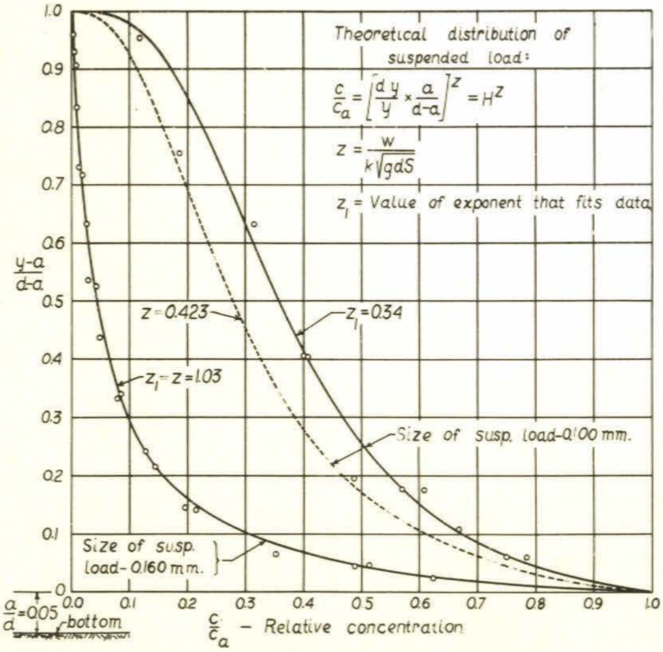


FIG. 3. EXPERIMENTAL AND THEORETICAL SEDIMENT DISTRIBUTION.

d = DEPTH OF FLOW
y = VARIABLE DISTANCE FROM BOTTOM
a = $0.05d$ = REFERENCE LEVEL
C = VARIABLE SEDIMENT CONCENTRATION
C_a = SEDIMENT CONCENTRATION AT REFERENCE LEVEL
w = SETTLING VELOCITY OF SEDIMENT PARTICLE IN STILL WATER
k = A UNIVERSAL CONSTANT
g = ACCELERATION OF GRAVITY
S = SLOPE OF CHANNEL

MOVABLE BED PHENOMENA

HANS ALBERT EINSTEIN

Two phases of the problem of sediment transportation can be treated analytically: (1) The problem of the vertical distribution of suspended matter in flowing water, which has been presented by Dr. Vanoni; (2) the problem of the movable bed.

A movable bed may be defined as a bed consisting of loose particles held in place solely by their own weight. If a flow occurs along this bed the particles will be moved from their places by the action of the flow in areas where local velocities are high, and will be redeposited in those portions of the bed where the local instantaneous velocities are lower.

The tendency of any particular flow to move these particles is well defined and measurable. In the case of sands and coarser particles such movement is called bed-load movement because the particles travel along the bed without ever being lifted to greater heights. Knowledge of this phenomenon has advanced to such a degree that, today, it is often possible to predict the approximate rates of movement to be expected for particular flows. This is important because of the great practical significance this type of sediment movement has in natural streams.

The importance of bed-load movement becomes most evident in streams where, in certain reaches, there exists a systematic discrepancy between the rate at which bed-load material is supplied by the watershed and the rate at which the flow is able to move it. The stream will adjust its load to its capacity by filling or scouring its bed and thus will alter its channel without regard for damage inflicted upon neighboring property. Fig. 1 shows a stream that receives more sediment than it can move. The bed grows higher with every flood. More and more water flows onto the floodplain, scattering coarse, unfertile sediment in orchards, fields and pastures. In addition to this direct damage from deposition there is indirect damage at points where flow concentration causes local scouring. If a considerable percentage of fine sediment prevents underground drainage, still further damage may result from swamping.

Fig. 2, on the other hand, shows a rather small stream that has not been supplied with as much sediment as it can transport. It has removed its entire bed and then has begun to cut into the underlying friable material. Thus it has developed an arroyo and very effectively separated the two sides of its valley. Simultaneously the watertable has been lowered, thus drying out the remaining soil of the valley bottom. Most soils are especially friable when dry and, consequently, tributaries of all sizes are encouraged to cut down to the elevation of the main stream, and the entire area may be rendered useless by the development of gullies.

Since the laws of the movable bed govern all this action, knowledge of them is essential. Such knowledge is even more important, however, as a basis for the design of artificial counter measures. We want to know how a stream's capacity to move bed material can be increased or decreased, and to what extent. We want to know how to estimate the sediment output of the watershed by studying the behavior of the stream itself. The Mountain Creek Report, supposed to be published soon by the Department, answers these questions for the small Piedmont stream and, in general, shows the method of attack for any stream. It shows that the condition of the bed can be characterized as the intensity of bed movement which, in turn, is a function of the flow. This relationship already is known for low and medium intensities of transportation. This range includes all conditions except those found in large streams having beds consisting of fine sand, and smaller streams with sandy beds and extremely high slopes. In both cases part of the bed sediment goes into suspension and results in what is really a combination of bed-load and suspended-load movement. This condition is found in many streams of the arid Southwest where rains of high intensity are combined with steep slopes and abundant supplies of sediment. A general study of this problem will be undertaken using the experimental flume in which the bed-load motion pictures were taken.

FIG. 1. AN ORANGE GROVE DAMAGED BY AN AGGRADING STREAM SEEKING A NEW CHANNEL.

FIG. 2. SMALL STREAMS THAT ARE NOT SUPPLIED AS MUCH SEDIMENT AS THEY CAN TRANSPORT MAY ERODE LARGE AND DEEP CHANNELS IF FRIABLE MATERIAL UNDERLIES THEIR BEDS.

A SIMPLE FLOW METER FOR PIPE OUTLETS

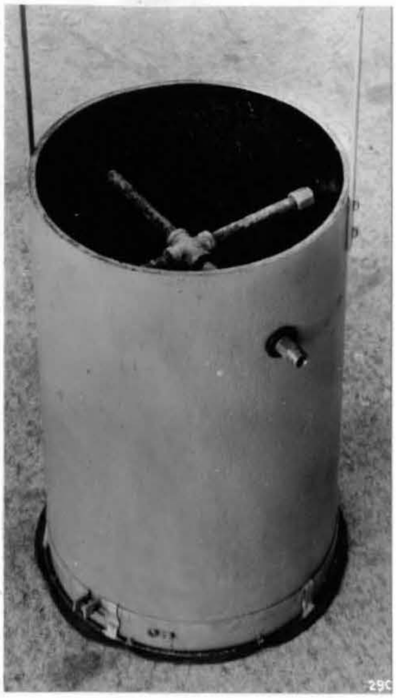
JAMES T. ROSTRON

The pipe flow meter as shown in Fig. 1 is a simple, portable device for measuring water discharging from vertical pipeline risers of irrigation systems. It is particularly advantageous for use in systems where flood-type irrigation is practiced because, under such circumstances, measuring devices using flumes or wiers are difficult to install. The pipe flow meter can normally be installed in about 15 minutes by one man and the discharge can be determined readily within 10% by means of a rating curve or table.

The present model of the meter is designed to function in irrigation risers which have the flow regulated by a "California Orange Valve" such as is shown in Fig. 2. To install the meter, the valve lid is removed by unthreading the screw and then the pipe is set over the valve base and pulled down with a screw similar to the one that holds the lid. The meter consists of a piece of pipe having a slightly larger diameter than the clear opening of the valve and has sufficient length so that the crest projects above the ground surface far enough to prevent the outflow from being submerged by water standing in the check. The model shown has an I.D. of 8 5/8", is 15" long and has a capacity of 0.2 to 2.5 c.f.s. The pressure in the water flowing through the meter is measured by the cross of small pipes seen in Fig. 1. These pipes have small openings on the underside. In the field the pressure is measured in a manometer, as illustrated in Fig. 3, and the flow can be determined immediately from a rating curve.

This meter has the advantage of having a rating curve that is very sensitive for the entire range of flows. This is due to the fact that at low discharges, the meter acts as a weir while at high discharges it acts as a nozzle. For a weir type discharge such as is shown in Fig. 3, practically the total pressure is due to static head, and the relation for Q vs. H is given by the equation $Q = CH^{1.5}$. But for nozzel or shooting type flow, atmospheric pressure exists at the cross section of the meter crest so that the pressure measured is due entirely to the velocity head. In this range the relation for Q vs. H is given by the familar expression $Q = C_1AV = C_1A\sqrt{2gH} = C_2H^{\frac{1}{2}}$. Each curve has a zone in which Q is sensitive to H. By joining these, a rating curve is secured which is sensitive to H over the entire range.

The total cost of this meter is approximately $20 and it weighs 30 pounds. Instruments of this same type can be adapted to pipes of different size and to different kinds of outlets. Their use need not be restricted to installations having the standard orange valve.



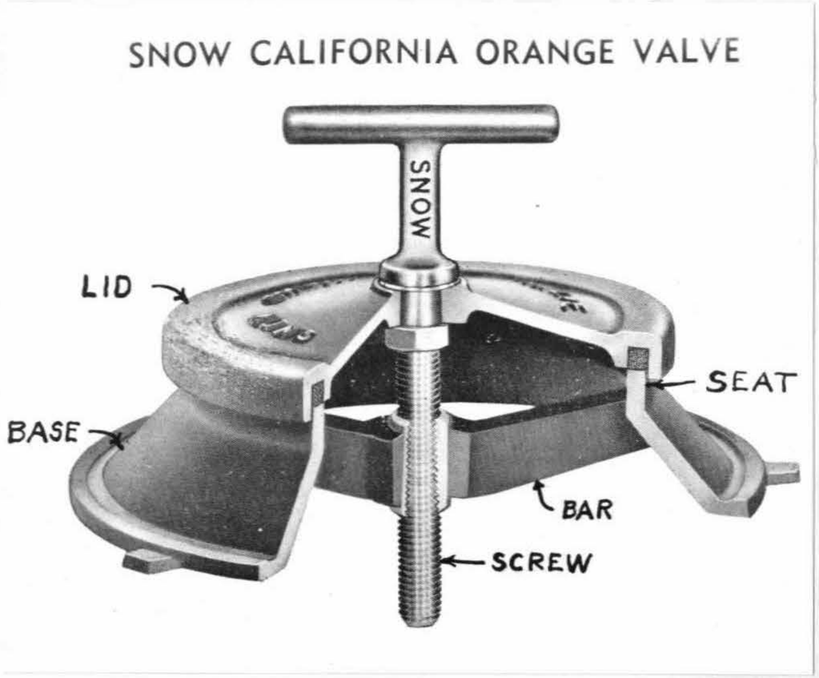


FIG. 1. PIPE METER FROM ABOVE. PRESSURE OPENINGS ARE LOCATED IN THE CROSS OF 1/8" PIPES.

FIG. 2. TYPICAL VALVE FOR REGULATING FLOW FROM IRRIGATION RISER. THE RUBBER GASKET OF THE METER SEATS ON TOP OF THE SLOPING SHOULDER OF THE VALVE BASE.

FIG. 3. IRRIGATION WATER BEING METERED IN AN ALFALFA FIELD. THE PRESSURE TUBE TO THE MANOMETER CAN BE SEEN ON THE LEFT SIDE OF THE METER. A FLOW OF 0.5 C.F.S. IS SHOWN.

THE BAFFLE TYPE ENERGY DISSIPATOR FOR PIPE OUTLETS

JAMES T. ROSTRON

The baffle type energy dissipator is designed to reduce the energy in high velocity pipe flow so that water may be discharged safely into an erodible channel. This structure can be adapted to meet the many field conditions encountered at pipe outlets draining terraces or ditches, highway culverts and drop inlet spillway outlets. Pipe sizes commonly used range from 10 to 48 inches and have flows from 10 to 250 c.f.s. discharging into channels of various widths.

Fig. 1 is a cross-sectional view of a small model with the elements of the structure indicated by the lettered signs. It shows the flow pattern at design discharge. The direction of flow is from right to left. The energy in the high velocity jet is effectively dissipated through turbulence created in the "baffle box" and "stilling pool", and the flow is spread uniformly over the entire channel cross section. The water may then be discharged with safety onto an erodible bed.

Through intensive model investigations, carried out in the flume shown in Fig. 2, the dimensions of the baffle box in particular and the structure as a whole were worked out very carefully to determine the smallest possible structure that would give satisfactory performance. Changing any one or several of the dimensions results either in poorer performance or in increased cost.

For a given set of field conditions all the information necessary to design a structure is given by the drawing, formulas and charts of Fig. 3. Local field conditions determine the discharge, structure width and total energy of the system.

The pipe size for a system including a baffle energy dissipator is calculated in the normal manner for any pipe line which has a submerged outlet. The amount of submergence is equal to the back-pressure created by the installation of the structure. The back-pressure is higher for narrow than for wide structures and its value is given by curve (b) in the design charts of Fig. 3.

The width of a proposed structure will usually be determined by the shape of the channel at the outlet. However when field conditions permit some lattitude as to structure width, it usually

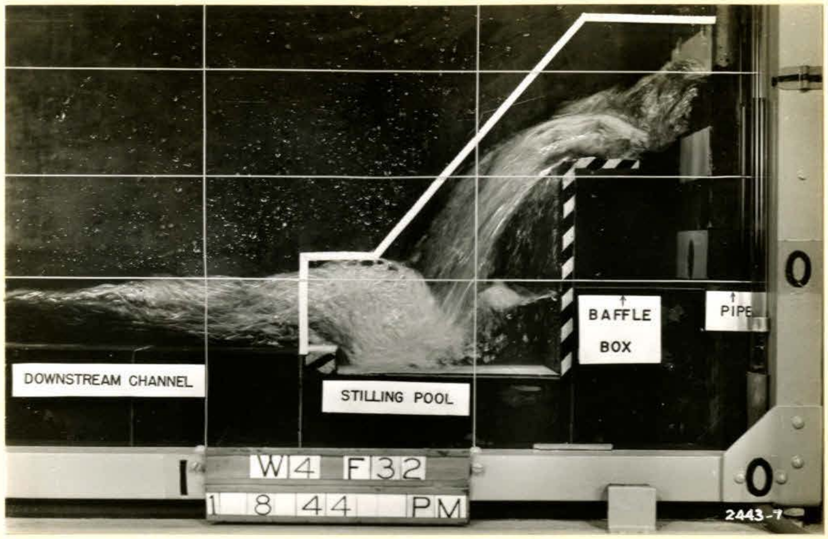


FIG. 1. A SMALL SCALE MODEL OF A TYPICAL BAFFLE STRUCTURE FOR A PIPE OUTLET, SHOWING FLOW PATTERN AT DESIGN DISCHARGE. A PROTOTYPE HAVING A 1.0' DIAMETER PIPE WOULD DISCHARGE 25 C.F.S., HAVE AN INFLOW VELOCITY OF 32 F.P.S. AND AN OUTFLOW VELOCITY OF 6 F.P.S.

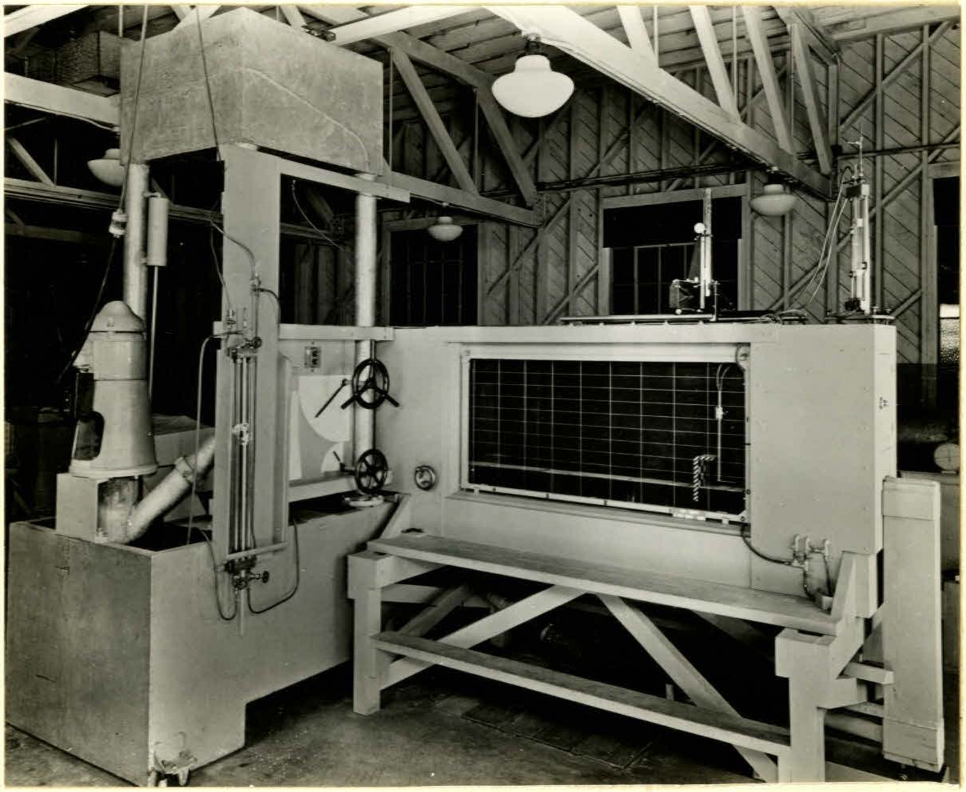


FIG. 2. FLUME IN WHICH EXPERIMENTS WERE CONDUCTED FOR THE DEVELOPMENT OF A BAFFLE TYPE ENERGY DISSIPATOR.

will be found that the most economical and satisfactory design is obtained when the structure is 6.0 pipe diameters wide.

This laboratory investigation was undertaken to develop a structure having a more economical energy dissipation system than those using the hydraulic jump. The baffle energy dissipator costs approximately half as much as a hydraulic jump structure. In addition it furnishes greater safety against failure from undermining or other causes over the entire range of discharges from zero to a considerable overload.

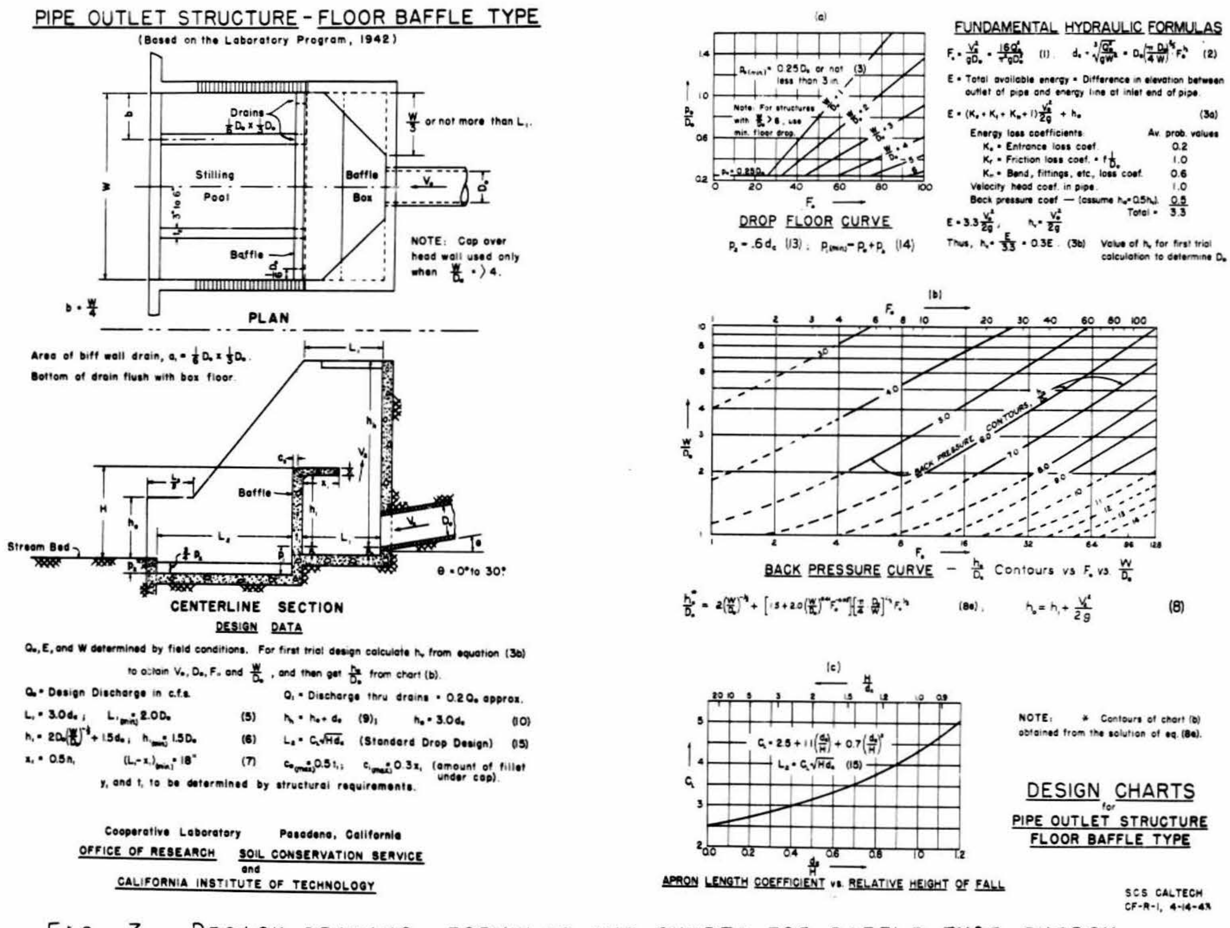


FIG. 3. DESIGN DRAWING, FORMULAS AND CHARTS FOR BAFFLE TYPE ENERGY DISSIPATOR FOR PIPE OUTLETS.

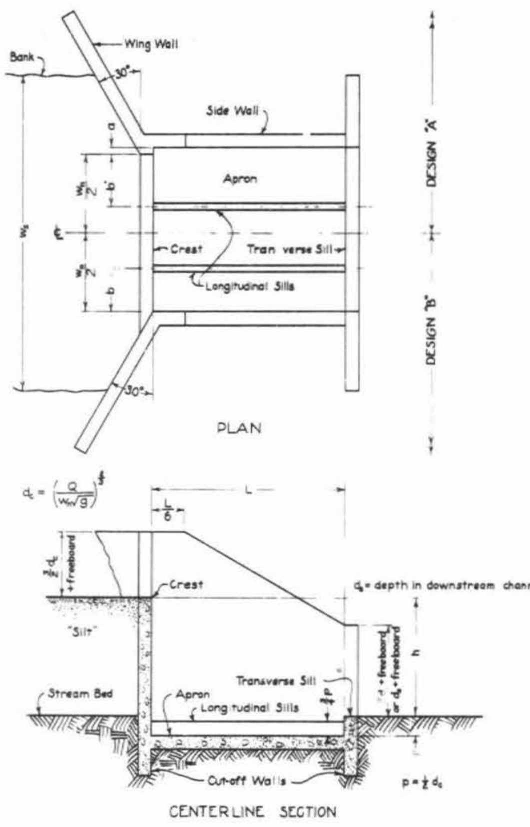
FLOW CONSIDERATIONS UNDERLYING THE DROP STRUCTURE DESIGN

ROBERT T. KNAPP

The purpose of this discussion is to examine the design for gully control drop structures developed at the Cooperative Laboratory and adopted by Regions Six and Seven as their regional standard. Figs. 1 and 2 show two structures for use under widely different conditions but both designed according to this standard. Figs. 3 and 4 give the details of the design. This design is composed of a small group of very simple elements, the proportions of which are specified in what may seem to be a quite arbitrary manner. However, when these recommendations for the individual elements are examined in the light of the laboratory findings, it develops that these proportions represent the optimum values that can be used and that deviations in either direction result either in loss in effectiveness or sacrifice of economy. Thus, it is evident that when the laboratory wishes to recommend a new design, it is not sufficient for it simply to ascertain that the structure performs satisfactorily. Instead, each element must be examined until the best proportions are determined. In general, to do this with reasonable certainty, it is necessary to become so intimately acquainted with the workings of the structure that the hydraulic function of each of the various elements becomes delineated. When this objective is reached, the research engineer is in a position to state not only what the effects will be of variations in the design elements, but why these effects occur. Such knowledge gives a firm foundation to the recommendations. It is the goal of the Cooperative Laboratory to approach as nearly as possible this type of solution for the field problems that are brought to it.

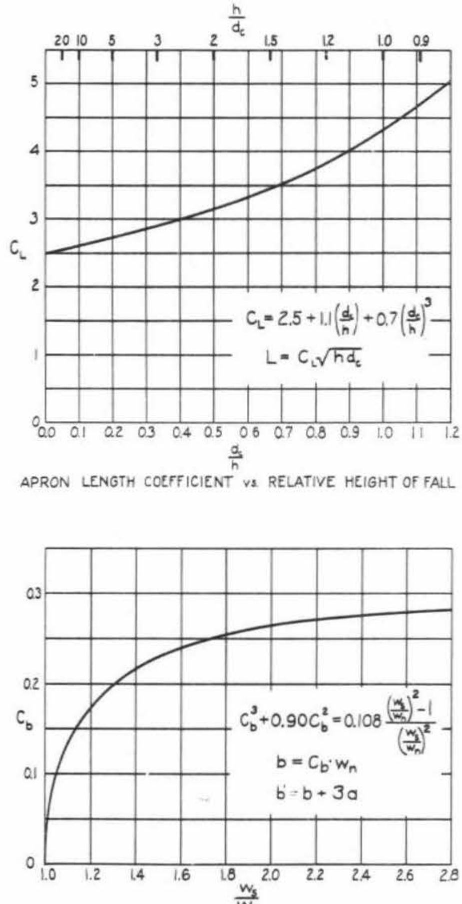
FIG. 1. A HIGH CAPACITY STRUCTURE FOR A LOW DROP.

FIG. 2. A LOW CAPCITY STRUCTURE FOR A HIGH DROP.



GULLY-CONTROL DROP STRUCTURE

Design "A" provides nappe ventilation through offset of the side walls from the notch edge as well as through lateral contraction of the flow at the crest.
Design "B" provides nappe ventilation through flow contraction alone.



SILL SPACING COEFFICIENT vs. LATERAL CONTRACTION RATIO

FIG. 3. FIG. 4.

DESIGN CHARTS FOR GULLY-CONTROL DROP STRUCTURE.

HYDRAULIC MODEL TESTS OF FOUR SPILLWAYS FOR REGION FOUR

VITO A. VANONI

In the spring of 1943 hydraulic model tests were made of four existing spillways for Region 4 of the Soil Conservation Service. Some damage had occurred to the spillways and the problem was to determine what modifications were necessary to repair the damage, and prevent its recurrence. In addition to answering these questions the model tests gave findings of general interest in connection with spillway design. The most important findings are:

1. Flow discharged at high velocity from a spillway into an erodible channel will cause excessive scour unless the energy of flow first is dissipated. Attempts to save money by avoiding the construction of energy dissipators will result in damage, failures, and expensive repair and protective work.
2. Serious flow disturbances are to be expected in a spillway having its entrance located in shallow water off to one side of a lake or reservoir. Locations of this type should be avoided if it is possible to do so.
3. Once the water has entered the spillway and has attained a high velocity, serious disturbances are caused by reduction of the width of the channel. Contraction of spillways is not recommended because of difficulties in safely handling disturbed flow.
4. Curves in spillways give rise to waves and disturbances that distort the flow, and should be used only when straight spillways are not feasible. When curves must be used, the designs should be developed by hydraulic model tests.

Fig. 1 shows one of the damaged spillways which was built without a stilling basin. Fig. 2 shows a 1 to 50 scale model of this same structure with modifications designed to correct the conditions that caused the failure shown in Fig. 1. The length of the structure has been reduced and a stilling basin installed. The two diagonal sills near the end of the structure are designed to distribute the flow uniformly across the spillway just before it enters the stilling basin. The serious disturbances in the spillway are caused by (1) the severe contraction of the width, and (2) the inlet asymmetry which results from locating the spillway in shallow water off to one side of the reservoir.

Fig. 3 shows the flow over a 1 to 40 scale model of another spillway. The flow into the spillway is symmetrical. However, the extremely severe contraction forces the flow towards the center where it forms a concentrated jet which causes the severe erosion seen in Fig. 4 as it discharges from the structure. The erosion pattern shown in this figure is very similar to the actual pattern observed in the field.

Fig. 5 shows a model of the structure recommended to replace the existing one. A hydraulic-jump stilling basin has been installed to dissipate the energy and to eliminate erosion. The spillway has been contracted only very slightly. Although this slight contraction causes some increase in velocity at the sides, it still gives satisfactory conditions. Further contraction is not recommended.

FIG. 1. A DAMAGED SPILLWAY. STRUCTURE IS 84 FT. WIDE AND IS DESIGNED FOR A DISCHARGE OF 6000 C.F.S.

FIG. 2. A 1 TO 50 SCALE MODEL OF SPILLWAY SHOWN IN FIG. 1 WITH MODIFICATIONS DESIGNED TO REPAIR DAMAGE AND PREVENT ITS RECURRENCE.

FIG. 3. A 1 TO 40 SCALE MODEL OF SPILLWAY SIMULATING A DISCHARGE OF 6400 C.F.S. NOTE THAT SIDEWALLS CONTRACT THE FLOW SHARPLY CAUSING WATER TO DISCHARGE FROM SPILLWAY AS A CONCENTRATED JET.

FIG. 4. EROSION PATTERN IN CHANNEL AFTER FLOW SHOWN IN FIG. 3. THIS PATTERN DUPLICATES FAIRLY CLOSELY THE ONE FOUND IN THE FIELD. THE SAND ON THE APRON OF THE MODEL STRUCTURE WAS SWEPT UPSTREAM FROM THE CHANNEL BED BY STRONG EDDIES.

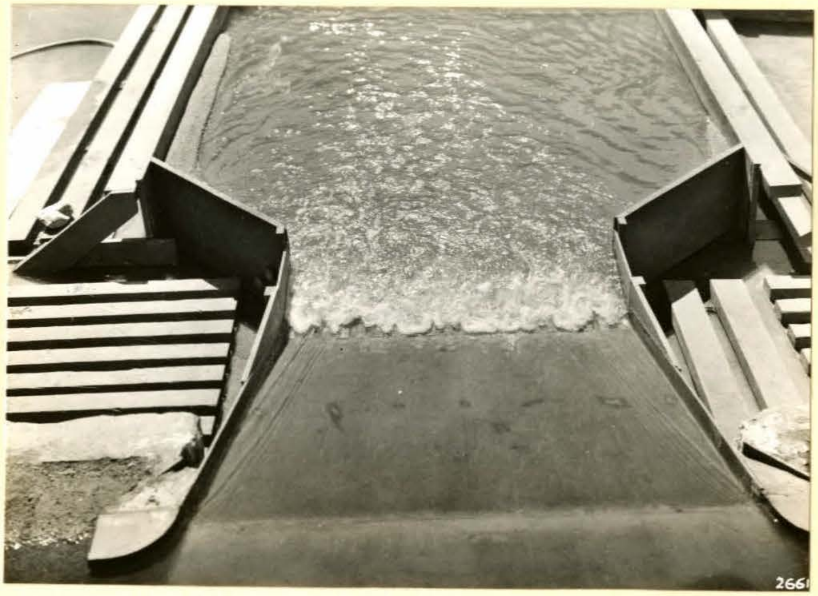


FIG. 5. LOOKING DOWNSTREAM AT MODEL OF STRUCTURE DESIGNED TO REPLACE THE SPILLWAY SHOWN IN FIGS. 3 AND 4. A HYDRAULIC-JUMP STILLING BASIN DISSIPATES THE ENERGY AND PRODUCES LOW-VELOCITY OUTFLOW THAT PRACTICALLY ELIMINATES EROSION. THE SMALL WAVES AT THE SIDES ARE CAUSED BY THE SLIGHT CONTRACTION OF THE SIDE WALLS.

PROBLEMS OF SPILLWAY DESIGN

HANS ALBERT EINSTEIN

In designing any dam for power, irrigation or flood control purposes the possibility that a flood may reach the reservoir when it is already full must be taken into consideration. A spillway is an emergency channel which is provided to bypass this flood safely, over or around the dam. A failure of the spillway usually causes the failure of the dam itself at a time when the reservoir is filled to capacity. Then a tremendous flood-wave rushes down the valley carrying death and destruction to the land the dam was meant to protect. Therefore, any spillway structure must be safe in every respect. On the other hand, in an entire lifetime the occasions when an ordinary spillway operates at full capacity usually can be counted on the fingers of one hand. Therefore, no one likes to spend any more money on a spillway than is absolutely necessary. Consequently the design should be safe and economical - two goals that can be achieved only if the flow can be predicted accurately in all parts of the structure.

The flow in a spillway is often extremely complicated as, for instance, when reservoir water of very low velocity converges through a wide and shallow entrance into a narrow channel, accelerates to high speed as it passes down the chute, and then is made to dissipate much of its kinetic energy before it can be discharged safely into the downstream channel. The details of such a flow are so complex that it is doubtful if any engineer could predict its behavior with sufficient accuracy to design a safe and economical structure unless he had the help of model tests. Without this help it is particularly difficult to determine whether or not the proposed structure will:

1. Have a satisfactory velocity distribution in the wide inlet.
2. Avoid diamond pattern waves in the chute. (These cause overtopping of sidewalls and undercutting of foundations.)
3. Provide for safe dissipation of energy in the stilling basin.

FIG. 1. THE USUAL DIAMOND PATTERN WAVES WHICH RESULT FROM POOR DESIGN.

FIG. 2. DIAMOND PATTERN WAVES CAN BE PREVENTED BY CORRECT DESIGN.

FIG. 3. EVEN WITH A SIDE ENTRANCE TO THE CHUTE, DIAMOND WAVES CAN BE PREVENTED.

FIG. 4. THE FLOOR TEETH IN THIS OTHERWISE GOOD STILLING BASIN ARE SHAPED IN SUCH A WAY THAT THEY CATCH FLOATING OBJECTS. THE TREMENDOUS SPRAY IN THE MODEL WAS CAUSED BY A LEAF THAT WAS ACCIDENTALLY CAUGHT.

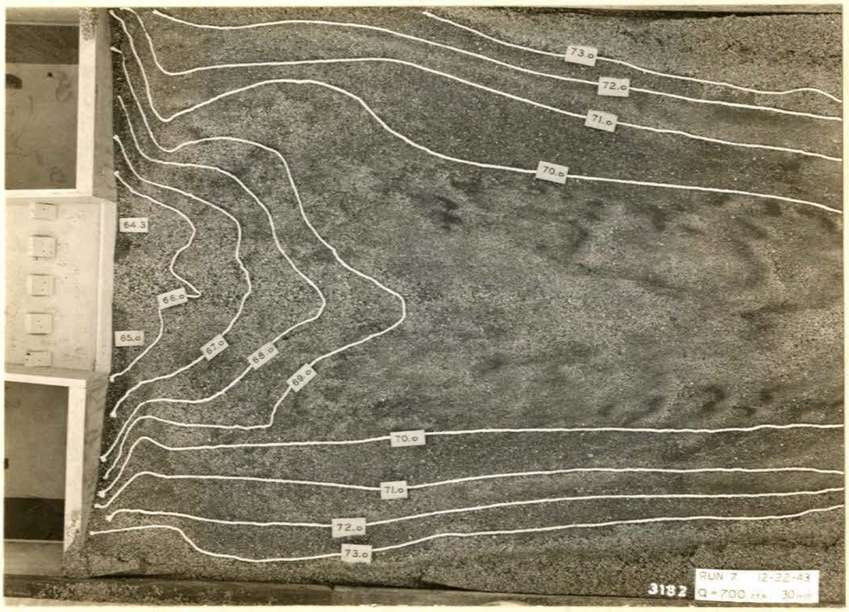


FIG. 5. TYPICAL SCOUR PATTERN IN THE CHANNEL BELOW A STILLING BASIN. THE EXTENT, SHAPE AND DEPTH OF SCOUR IS A MEASURE OF THE EFFECTIVENESS OF THE STILLING BASIN.

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